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EFFECT OF ELEVATED TEMPERATURES ON STRENGTH PROPERTIES OF REINFORCED PLASTIC LAMINATES

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U.S. Department of Agriculture, Madison, Wisconsin;
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NOTICES

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FOREWORD

This report was prepared by the Forest Products Laboratory. Work here reported was sponsored by the Directorate of Materials and Processes under USAF Contract No. DO 33(616)61-06. This contract is carried under Project No. 7381, "Materials Application," Task No. 738103, "Data Collection and Correlation." It is administered under the direction of the Directorate of Materials and Processes, Deputy Commander/Technology, Aeronautical Systems Division, with Mr. T. J. Reinhart, Jr., acting as project engineer.

This report covers an evaluation of a number of products under specific conditions. The materials may not have been developed or intended by the manufacturer for the conditions to which they have been subjected. Any failure or poor performance of a material is therefore not necessarily indicative of the utility of that material under less stringent conditions or for other applications.

ABSTRACT

Several reinforced plastic laminates that have shown promise of having good strength properties at elevated temperatures have been investigated to determine their strength within their useful range of temperature and duration of exposure. Results of tension, compression, and interlaminar shear evaluations are summarized for six laminates after exposure to temperatures ranging from room temperature to 1,000° F. and soak periods ranging from about 2 minutes to 1,000 hours.

The results show that the strength usually decreases immediately with application of heat. Further application of heat at constant temperature, however, sometimes results in an increase in strength, but continued exposure at the higher temperatures ultimately results in a complete loss of strength. Exceptions and various degrees of degradation depend on the kind of material, the temperature, and the period of exposure. Hence, curves are presented for six materials, three mechanical tests, and a range of duration of exposure, so that each may be judged separately.

This technical documentary report has been reviewed and is approved.

D. A. SHINN
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Applications Laboratory
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I. INTRODUCTION

Reinforced plastics are continually being developed to meet the demands for improved performance with increases in operating temperature. As they are being developed, there is the paramount need for expanding the knowledge of the strength properties of the reinforced plastic as a structural material. Strength data that show the effect of elevated temperatures for various periods of time on strength properties of reinforced plastics are needed for design of structures made with heat-resistant plastic materials.

In the development of reinforced plastic systems, the blends and treatments are generally made to meet specific requirements so that strength evaluations are made at specific conditions. However, in order to provide useful design criteria over a large temperature range and long periods of exposure, the Forest Products Laboratory, in cooperation with Aeronautical Systems Division and material manufacturers, is engaged in a program of material evaluation. The material tested may not have been developed or intended by the manufacturer for the experimental conditions to which it was subjected, so performance reported here does not necessarily indicate the utility of the material under less stringent conditions or for other applications.

Data from seven reports on reinforced plastic laminates are summarized.[1] The work was undertaken to provide data on the strength of plastic materials at elevated temperatures from room temperature to 1,000° F. and after exposures of from 2 minutes to 1,000 hours. The effect of exposure on strength was determined by subjecting the material to various elevated temperatures and then exposing it at the constant temperature in an unstressed condition. After an arbitrary duration of exposure (soak period), the material was subjected to increasing loads at the constant exposure temperature until failure occurred.

The work summarized here presents the results of tension, compression, and interlaminar shear evaluations for six different reinforced plastic laminates. The reference literature[1] for this paper also presents properties pertaining to weight loss, flexure, edgewise shear, bolt bearing, and stress-rupture. The effect of various exposures on these mechanical strengths is generally similar to those in tension, compression, and interlaminar shear.

Manuscript released by author May 1962 for publication as an ASD Technical Documentary Report.

[1]Listed as references on page 7.

II. LAMINATES

The six reinforced plastic laminates currently evaluated in this program are:

(1) A silicone resin with glass-fabric reinforcement (DC 2106 and 181 heat-cleaned glass fabric)

(2) A phenolic resin with glass-fabric reinforcement (CTL-91LD phenolic resin and 181-A1100 glass fabric)

(3) A phenolic resin with asbestos-felt reinforcement (R/M Pyrotex Felt Style 41-RPD)

(4) An epoxy resin with glass-fabric reinforcement (Epon 1031 resin and 181-Volan A glass fabric)

(5) A phenyl-silane resin with glass-fabric reinforcement (CTL 37-9X resin and 181-A1100 glass fabric)

(6) A silicone resin with asbestos-felt reinforcement (R/M Pyrotex Felt Style 45-RPD)

The resin manufacturers and laminaters contributed to this project by supplying fabricated panels. General fabrication information for these laminates is presented in Table 1.

III. EVALUATION PROCEDURE

The material suppliers furnished the Forest Products Laboratory with sufficient laminates about 1/8 inch thick to make the comprehensive study in this program. The quality of the laminates was first determined by a strength evaluation in flexure and compression at (1) room temperature; (2) 1/2-hour soak at 500° F. and test at 500° F.; and (3) after 192-hour soak at 500° F., test at 500° F. Only material that met military standards was evaluated in a comprehensive program.

There were five replications of individual coupons for each environmental condition. The temperatures of those environmental conditions were room temperature and at 100° F. increments from 300° to 1,000° F. The periods of soak at a constant temperature varied from 2 minutes to 1,000 hours, and the number of periods of soak varied from three to seven, depending on the number of conditions necessary to define the strength-time trend at a constant temperature.

Tension and compression specimens were soaked for periods from 2 minutes to 1,000 hours; interlaminar shear specimens, from 1/2 hour to 1,000 hours.

Heating was done in electric ovens or by specially built plate heaters. Ovens were 24 by 24 by 36 inches overall and had heating coils in the sidewall, a circulating fan in the back wall, and a front access door for admittance to the work space.

For exposure periods of 1/2 hour and less, heat was applied to the faces of tension and compression specimens by plate heaters. At exposure periods of 2, 10, and 30 minutes, specimens were heated, soaked, and loaded while constant temperature was maintained with these heaters. Interlaminar shear specimens were heated for 1/2 hour in an oven that was located in a universal testing machine, and they were then loaded to failure.

For exposure periods greater than 1/2 hour, specimens were generally placed in conditioning ovens, soaked for the desired period, and then cooled and placed in a desiccator. Just before testing, interlaminar shear specimens and some of the tension and compression specimens were placed in an oven that was located in the testing machine, reheated, and loaded to failure. Other tension and compression specimens were encased within plate heaters, heated, and loaded to failure.

The tensile properties were determined according to Federal Specification L-P-406b, Method 1011, and ASTM Method D638-52T. The specimens were necked down from rectangular strips 1/8 inch thick, 3/4 inch wide, and 9-3/8 inches long so that the contour of the reduced section conformed to that given in Federal Specification L-P-406b, Method 1011, figure 1011A, Type 2. The net section, which was 1/4 inch wide and 2-1/4 inches long, was connected to the shanks by arcs with 3-inch radii. The specimens were loaded through Templin-type grips at a head speed of about 0.04 inch per minute.

The compressive properties were determined from specimens that had been necked down from strips 1/8 by 3/4 by 3-1/8 inches to a net section 1/2 inch wide and 1-1/4 inches long, with an arc of 2-inch radius in the transition portion. The bearing ends of these specimens were ground smooth and parallel to each other and perpendicular to the specimen length. The specimens were supported in a compression jig. The jig, the specimen's net section, and the specimen's length conformed to Federal Specification L-P-406b, Method 1021.1. The widened bearing ends, however, modified the contour and force failures in the net section. The load was applied through a spherical loading head at a rate of head motion of 0.009 inch per minute.

The specimen that was used to obtain the interlaminar shear strength conformed to Aircraft Technical Committee Report ARTC 11, "Test Methods for Structural Plastic Laminates at Low and Elevated Temperatures," Test Method VI. The specimens were rectangular strips 1/8 inch thick, 1 inch wide, and 8 inches long. Two parallel cuts--one on each opposite face of the specimen and 1/2 inch apart, measured from the inside edges of the cuts--were made across the entire width of the specimen. The central portions of the specimens were supported by steel

plates 1-1/2 inches wide by 1/4 inch thick by 3 inches long. These plates were the faces of a "C" clamp and were adjusted finger tight against the specimen by a knurled wheel and bolt. The tensile load was applied at a rate of head speed of about 0.05 inch per minute.

The individual strength values from five replications were averaged, and the average values were plotted on semilogarithmic coordinates with strength as ordinate (uniform scale) and time as abscissa (log scale). Smooth curves of constant temperature were drawn through the plotted points, thus establishing trends of strength as affected by the soak period at constant temperature. From such strength-temperature-time curves, strengths at constant periods of exposure were observed and replotted on Cartesian coordinates of strength versus temperature. Such strength curves at constant soak periods are presented for discussion on six laminates and three mechanical tests (Figs. 1 through 6). The ordinate of these figures is strength as percent of the room temperature strength. Thus even though there is a wide variation in absolute unit room-temperature strength for these laminates, the effect of temperature, for comparison, is shown with a common denominator. The abscissa is temperature on a uniform scale from 0° to 1,000° F.

IV. DISCUSSION OF RESULTS

In general, the results of the tests show that the strength properties decrease with the first application of heat. Each mechanical strength property for each material, however, is affected to a different degree. The object of these investigations was to ascertain and present the degree of strength retention after various intensities of exposure, but not to discuss the merits and potential value of the individual mechanical tests or the individual materials.

The various curves presented in Figures 1 through 6 show how much strength varies with continual application of heat. The quantity of heat to which the materials were subjected is related to the temperature of exposure and the duration of exposure. The effect of these two variables on strength is a three-dimensional relationship. Even though the data were obtained at various constant temperatures and variable periods of exposure as an experimental expedient, the coordinates presenting the data are stress as the dependent variable and temperature as the independent variable; the family of curves on the figures represents the relationship of stress retention at constant periods of exposure for various temperatures. The range of variables was from 75° to 1,000° F. and from 2 minutes to 1,000 hours of exposure.

The maximum strengths retained after exposure are presented for three types of mechanical tests--tension, compression, and interlaminar shear. Experiments

show that in general these three types of mechanical tests produce a good cross section of the mechanical behavior of a laminate. The tension test results usually reflect the behavior of the reinforcing media. Absolute strength values as well as relative retained strength values are usually high for this mechanical test. The interlaminar shear test results usually reflect the behavior of the resin or bonding agent between laminations of the reinforcing media. Absolute strength values are very low and relative values usually low in comparison with tensile values. The test results of compression, flexure, and tension at 45° to the principal axis, which represents effects from a combination of elements and forces, are usually intermediate between tension at 0° and interlaminar shear values. Only one type of intermediate test, however, is presented here--the axially loaded compression test.

After the first application of heat, the various curves show that some materials continue to decrease in strength with increases in temperature, while others show increases in strength. The latter trend exists until there is a critical exposure condition, after which the components degrade or decompose, resulting in strength losses that are not recoverable as were the losses due to the first application of heat. Examples of this behavior are presented in tension curves of Figures 2, 4, and 5, compression curves of Figures 3 and 6, and shear curves of Figure 6. This behavior is therefore not confined to one material or one type of mechanical test. After the critical exposure condition, strength losses continue until there is a complete loss in strength for most materials. The exception to this trend appears to be the silicone resin combinations, especially the silicone asbestos combination (Fig. 6, compression curves) to which high-temperature applications tend to fuse the components after volatiles have evaporated.

As would be expected, the basically different resins--silicone, phenolic, epoxy, and phenyl-silane--with their respective reinforcements and finishes, have different degradation and critical exposure characteristics. The relationships between strength and time at temperature are similar in form for the phenolic and phenyl-silane laminates that were reinforced with glass fabric (Figs. 2 and 5). On the other hand, curves for phenolic-asbestos and silicone-asbestos laminates are quite different in form (Figs. 3 and 6).

V. SUMMARY

Reinforced plastic laminates vary widely in different strength properties. The effect of the reinforcement is usually reflected by tensile properties parallel to the principal axis; the effect of resin or bonding agent, by interlaminar shear; and the combined effect of reinforcement and resin, by compression, flexure, or tension at 45° to the principal axis.

The effect of elevated temperature and time at temperature varies greatly with different materials. Usually there is an immediate loss of strength as temperature is increased, but continued increases in temperature sometimes result in a temporary recovery or gain in strength. Continued exposure to 1,000 hours at temperatures to 1,000° F. usually results in a substantial loss of strength. Some resin systems in the material completely disappear, while others seem to fuse with the reinforcement.

Data from evaluations of six different reinforced plastic laminates are summarized in this report. The materials investigated had been developed or intended by the manufacturer to meet specific conditions and some performance reported here is possibly under conditions outside their intended range. The experimental conditions, however, demonstrate their utility for temperatures up to 1,000° F. and durations up to 1,000 hours. Curves show how tensile, compressive, and interlaminar shear strength varied with temperature and duration of exposure at that temperature. General conclusions cannot be made because of the wide range of materials and strength properties. Each material can be judged, however, in terms of its capabilities to meet certain strength requirements after a period of exposure to an elevated temperature.

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Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (CTL-91LD Phenolic Resin and 181-A1100 Glass Fabric) WADC Tech. Rept. 59-569. January 1960.

(2) __________
Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (Phenolic-Asbestos, R/M Pyrotex Felt Style 41-RPD). WADD Tech. Rept. 60-177, Part I. June 1960.

(3) __________
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(4) __________
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(5) __________
Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (CTL 37-9X Resin and 181-A1100 Glass Fabric). ASD Tech. Rept. 61-482. March 1962.

(6) __________
Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (Silicone-Asbestos, R/M Pyrotex Felt Style 45-RPD). ASD-TDR-62-406. [In Press]

(7) __________, and Kimball, Kenneth E.
Strength Properties of Reinforced Plastic Laminates at Elevated Temperatures (DC 2106 Resin and 181 Heat-Cleaned Glass Fabric) WADC Tech. Rept. 59-229. September 1959.

Table 1.--FABRICATION AND PHYSICAL PROPERTY DATA ON HEAT-RESISTANT PLASTIC LAMINATES[1]

Combination	Resin notation	Reinforcement notation	Number of plies	Laminating: Pressure	Laminating: Temperature	Laminating: Time	Postcure: Temperature	Postcure: Time	Resin content: Initial	Resin content: Final	Barcol hardness	Specific gravity
				P.s.i.		Min.		Hr.	Percent	Percent		
Silicone and glass	DC 2106	181-Heat Cleaned	14	30	175° C.	30	250° C.	48	....	36.2	59	1.81
Phenolic and glass	CTL-91LD	181-A1100	14	200	270° F.	45	250° F.	24	40 ±2	37.3	86	1.79
							300° F.	24				
							350° F.	24				
Phenolic and asbestos[2]	R/M 984-RPD	R/M Pyrotex Style 40-RPD	44	400	300° F.	30	300° F.	24	27 ±3	34.0	72	1.88
							350° F.	24				
							400° F.	8				
Epoxy and glass	Epon 1031	181-Volan A	14	300	350° F.	30	400° F.	1	40	36.2	74	1.85
Phenyl-silane and glass	CTL-37-9X	181-A110	14	200	275° F.	35	250° F.	24	37 ±2	26.0	78	1.97
							300° F.	24				
							350° F.	24				
							400° F.	24				
Silicone and asbestos[3]	DC 2106	R/M Pyrotex Style 40-RPD	26	1,000	300° F.	30	90° C.	16	35.5	20.0	56	1.68
							125° C.	2				
							150° C.	2				
							175° C.	2				
							200° C.	2				
							225° C.	2				
							250° C.	14				

[1]All parallel-laminated.

[2]R/M Pyrotex Felt Style 41-RPD.

[3]R/M Pyrotex Felt Style 45-RPD.

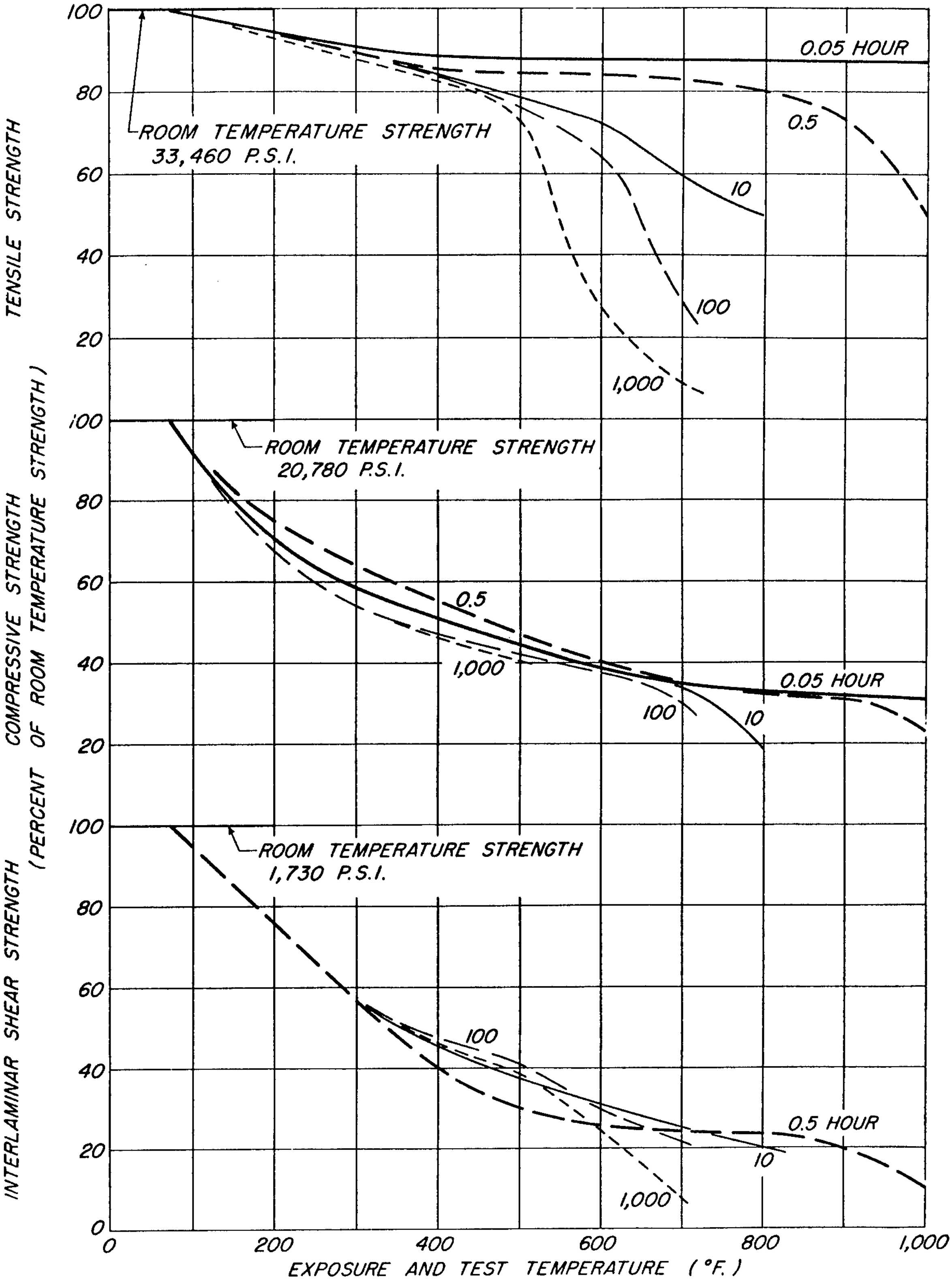

Figure 1. --Mechanical Strength at Elevated Temperatures and Various Soak Periods for DC 2106 Silicone Resin and 181 Heat-Cleaned Glass Fabric.

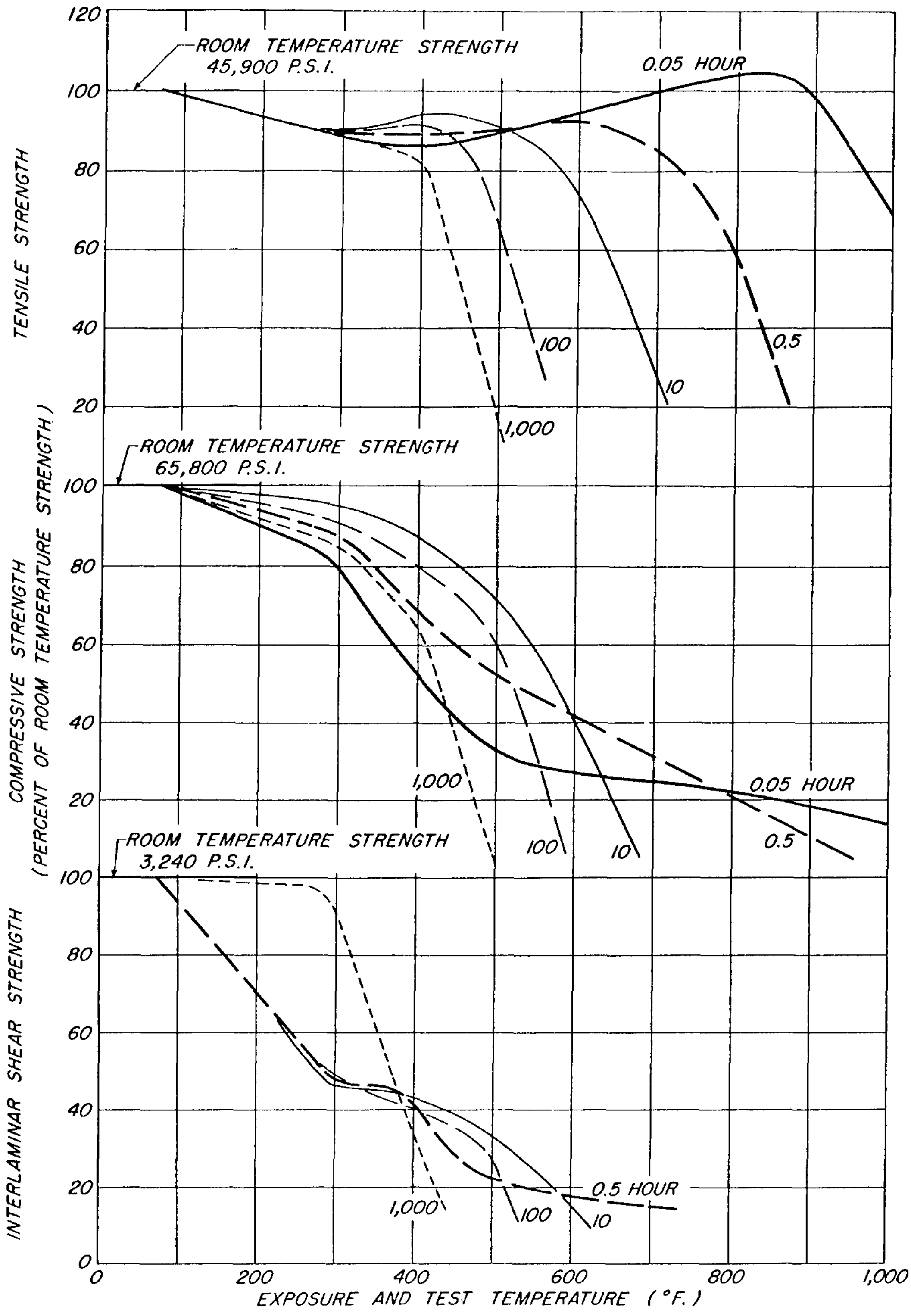

Figure 2. --Mechanical Strength at Elevated Temperatures and Various Soak Periods for CTL-91LD Phenolic Resin and 181-A-1100 Glass Fabric.

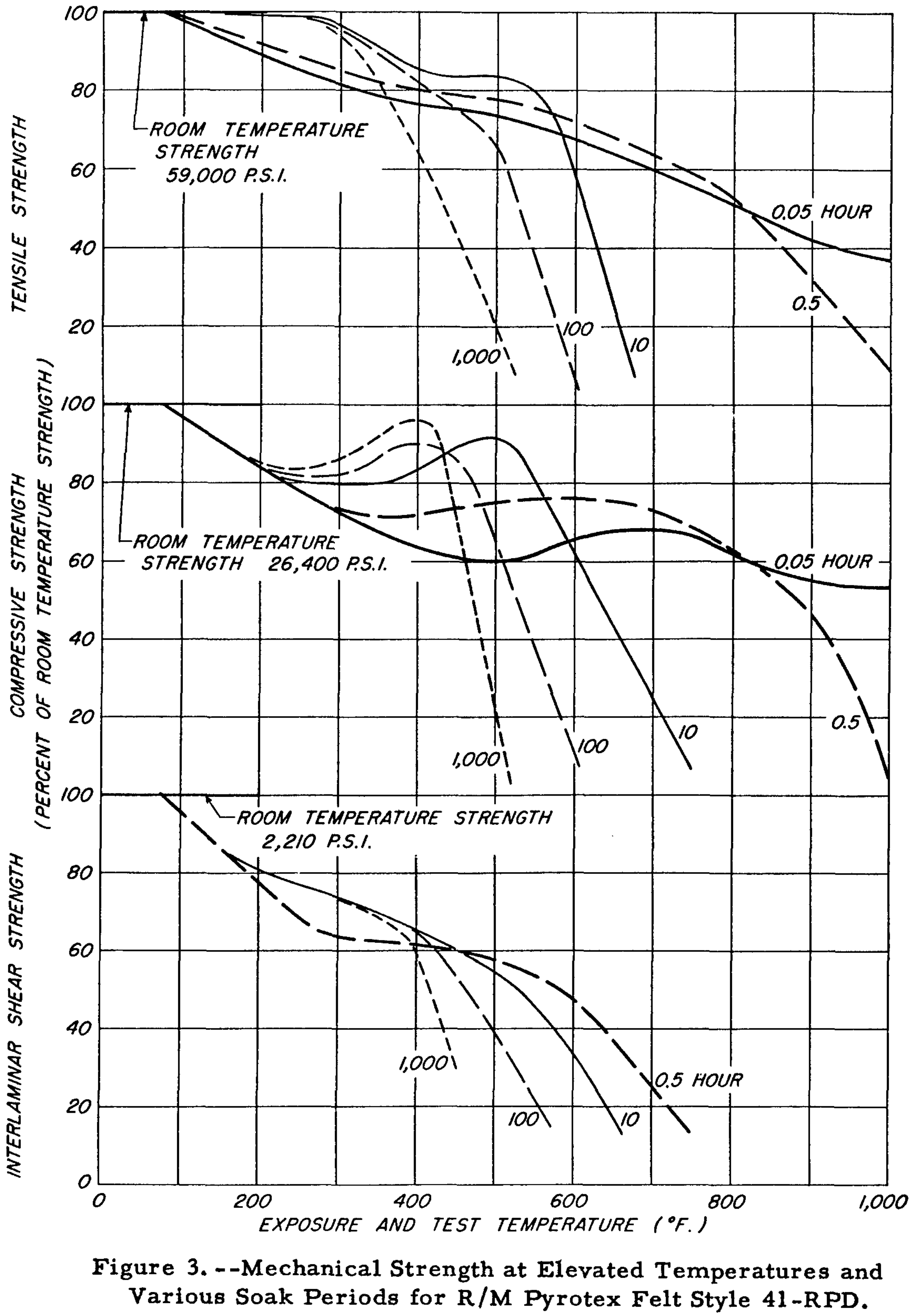

Figure 3. --Mechanical Strength at Elevated Temperatures and Various Soak Periods for R/M Pyrotex Felt Style 41-RPD.

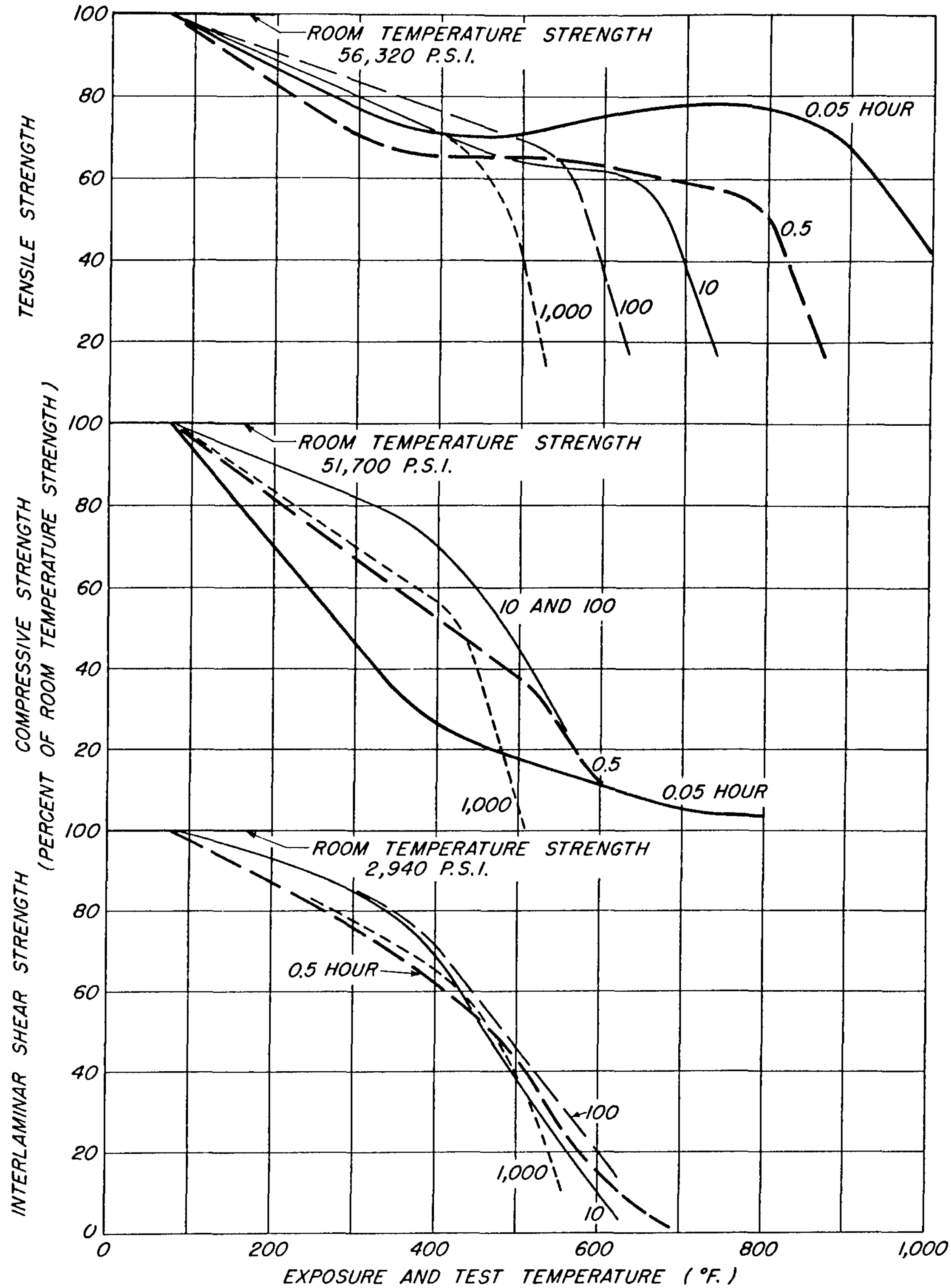

Figure 4. --Mechanical Strength at Elevated Temperatures and Various Soak Periods for Epon 1031 Epoxy Resin and 181-Volan A Glass Fabric.

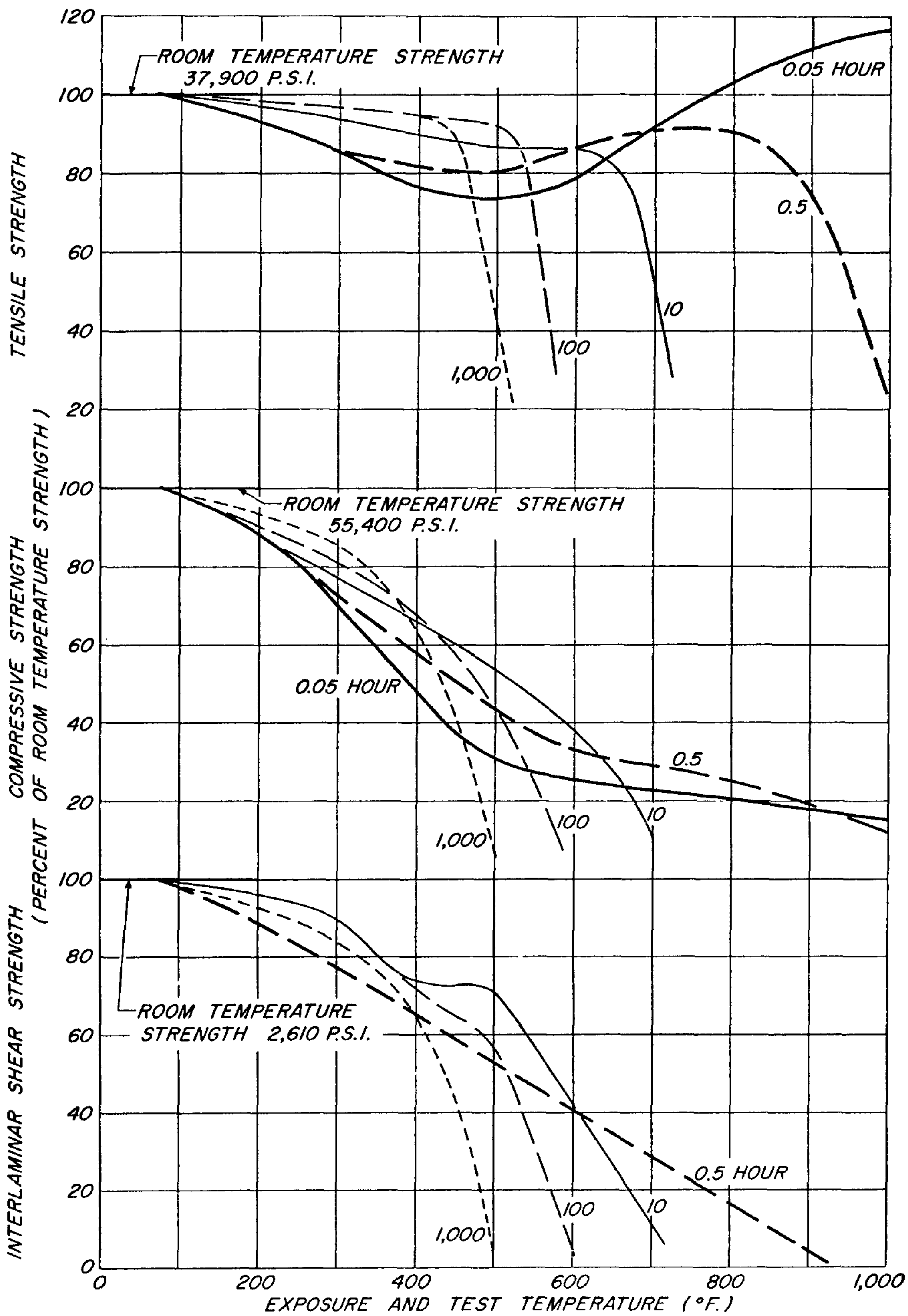

Figure 5. --Mechanical Strength at Elevated Temperatures and Various Soak Periods for CTL-9X Phenyl-Silane Resin and 181-A1100 Glass Fabric.

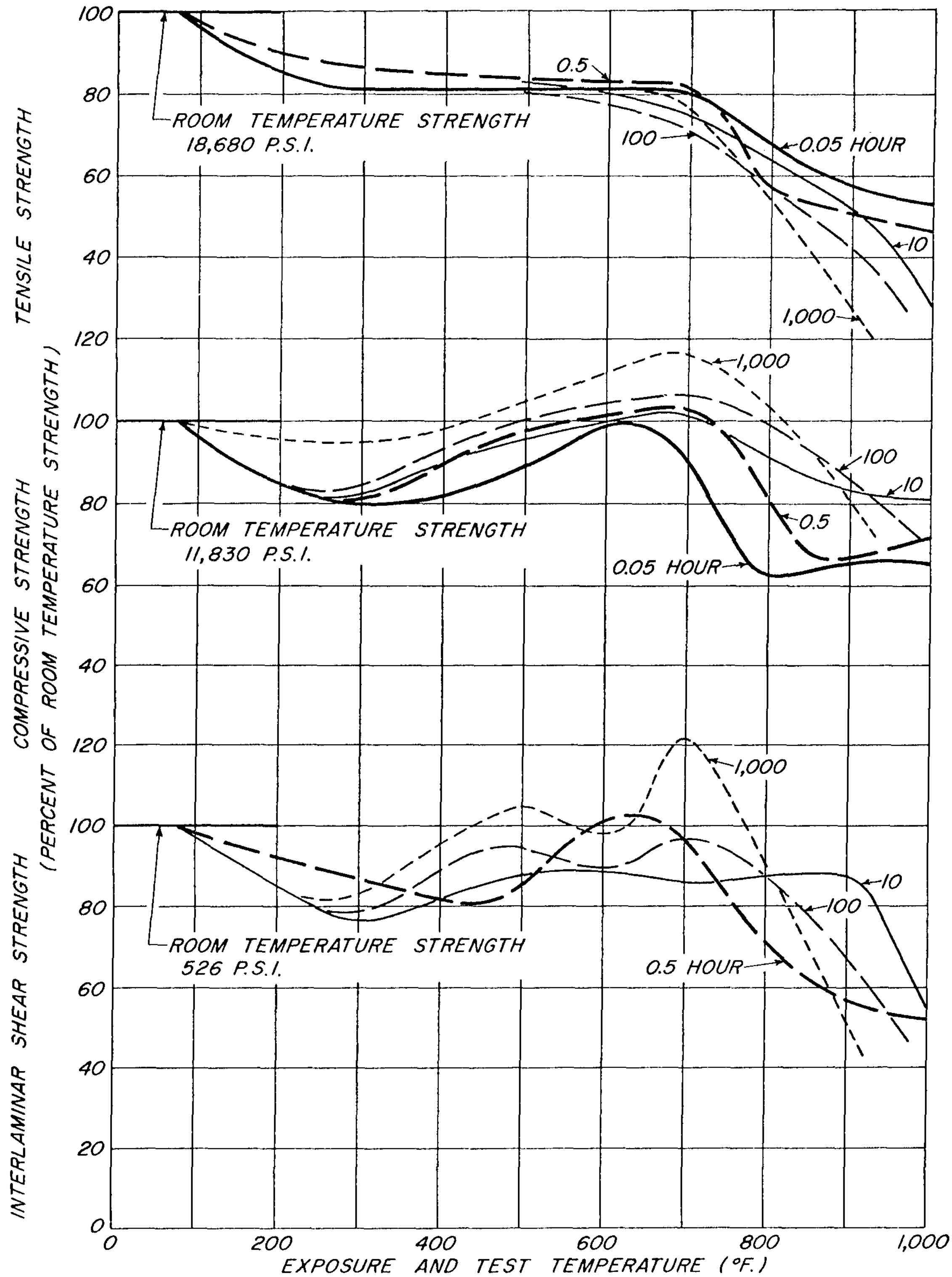

Figure 6. --Mechanical Strength at Elevated Temperatures and Various Soak Periods for R/M Pyrotex Felt Style 45-RPD.

Aeronautical Systems Division, Dir/Materials and Processes, Applications Lab., Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-629. EFFECT OF ELEVATED TEMPERATURES ON STRENGTH PROPERTIES OF REINFORCED PLASTIC LAMINATES. Final report, Oct 62, 14 p. incl. illus., table, and 7 refs.

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